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Galetti

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(54) **NAVIGATION SYSTEM AND METHOD**

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H04N 23/90 (2023.01)
G06T 7/73 (2017.01)

(52) **U.S. Cl.**
CPC ***G06T 7/74*** (2017.01); ***H04N 23/90*** (2023.01); *G06T 2207/30252* (2013.01)

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CPC B64C 39/024; B64C 19/00; B64C 25/10; B64C 27/08; B64C 39/02; B64C 25/52; B64C 2025/008; B64C 25/12; B64C 25/24; B64C 25/34
USPC 348/116
See application file for complete search history.

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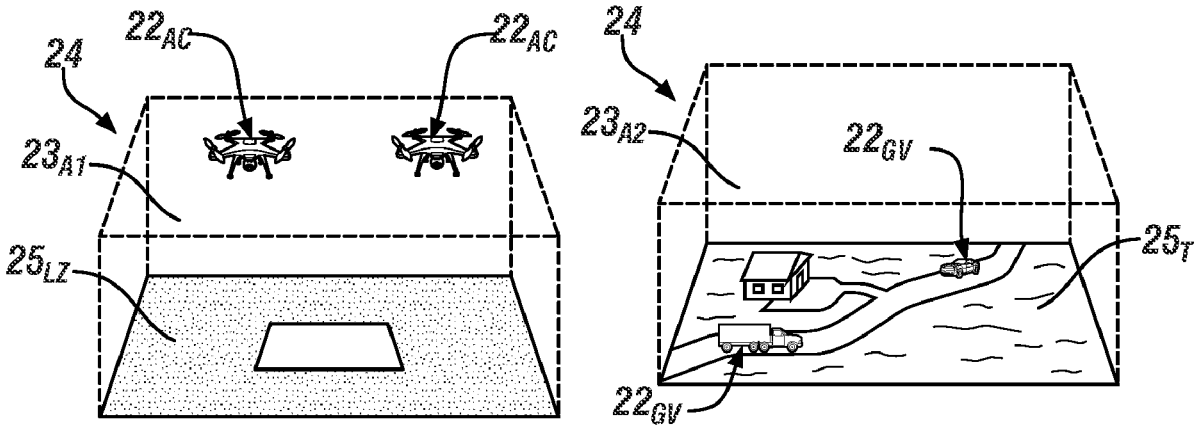
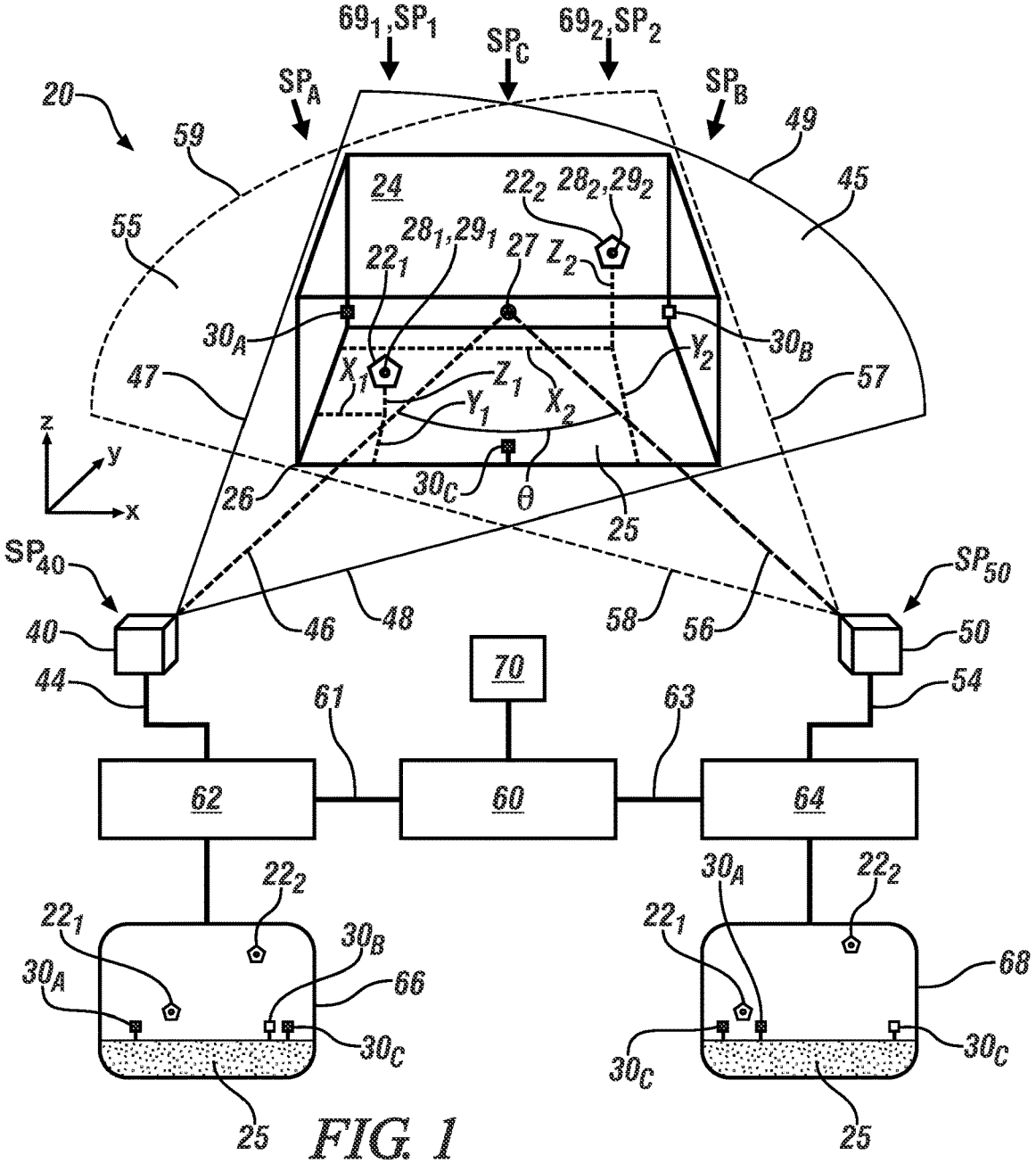
(57) **ABSTRACT**

A navigation system for one or more vehicles located within a control volume includes: a first camera configured to observe the one or more vehicles and first, second and third reference points disposed within the control volume and having first, second and third known spatial positions, respectively, the first camera being further configured to produce a first output signal from observation of the observed vehicles and reference points; a second camera configured to observe the one or more vehicles and the first, second and third reference points, the second camera being further configured to produce a second output signal from observation of the observed vehicles and reference points; and a processor operatively connected with the first and second cameras and configured to determine a respective spatial position for each of the one or more vehicles from the first and second output signals.

19 Claims, 8 Drawing Sheets

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30_B
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44
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61
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54
62
60
64
22_2
22_1
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66
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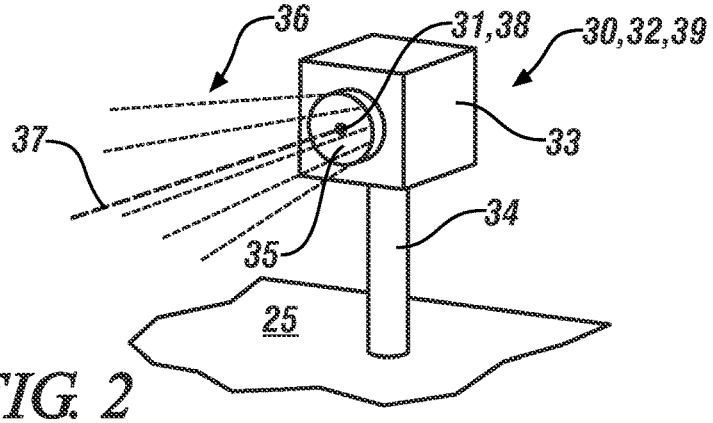
30_A
22_2
22_1
68
30_C
30_C
25

FIG. 1


36
31,38
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33
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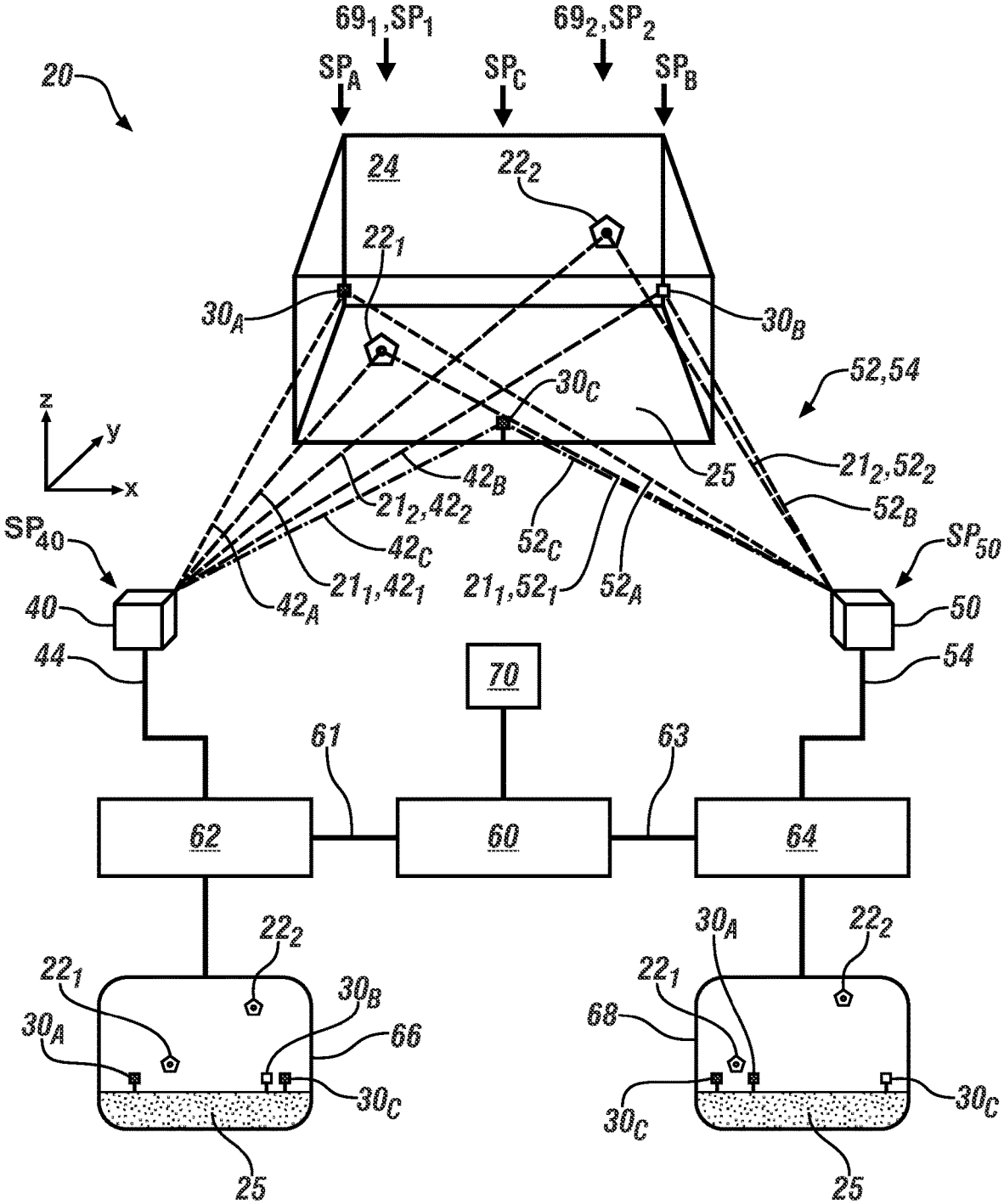
35
25

FIG. 2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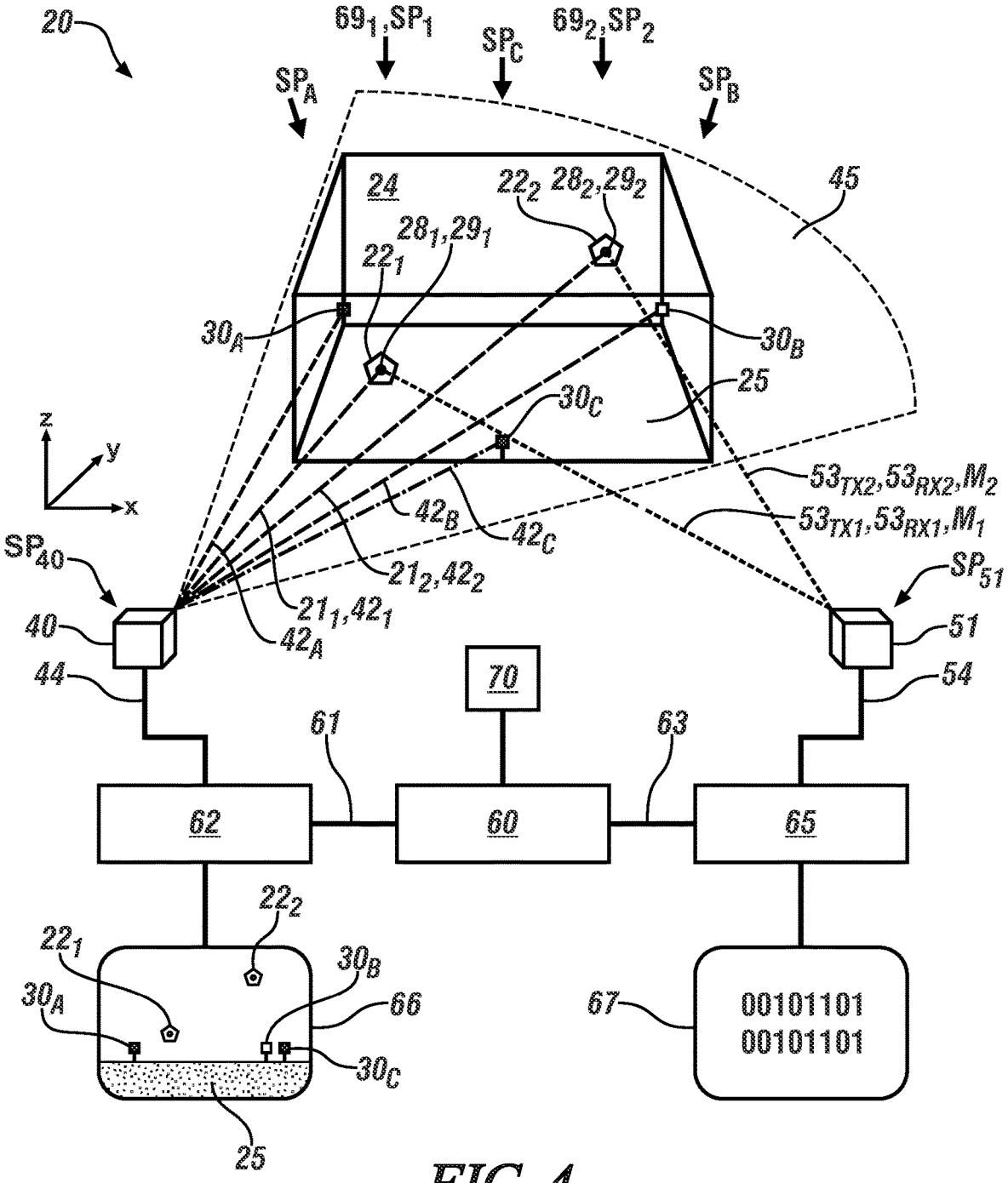
52,54
z
y
x
42_B
21_2,42_2
42_C
52_C
25
21_2,52_2
52_B
SP_{40}
SP_{50}
42_A
21_1,42_1
21_1,52_1
52_A
40
50
44
54
70
61
63
62
60
64
22_2
22_1
30_B
30_A
66
30_C
25
30_A
22_2
22_1
68
30_C
30_C
25

FIG. 3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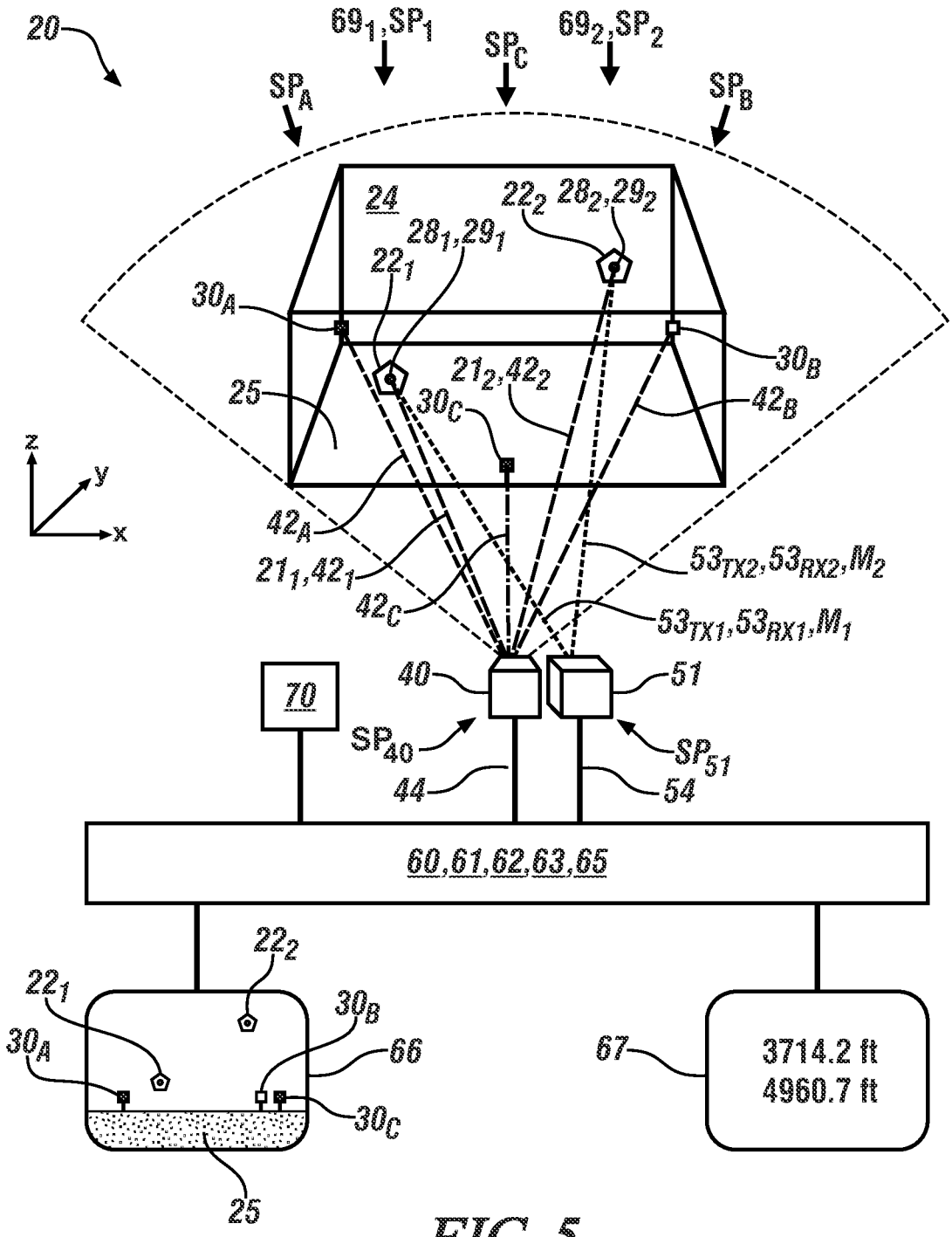
SP_A
SP_B
24
22_2 28_2,29_2
45
28_1,29_1
22_1
30_A
30_B
25
30_C
z
y
x
53_{TX2},53_{RX2},M_2
53_{TX1},53_{RX1},M_1
42_B
42_C
SP_{40}
SP_{51}
21_2,42_2
21_1,42_1
42_A
40
51
44
54
70
61
63
62
60
65
22_2
22_1
30_B
30_A
66
67
00101101
00101101
30_C
25

FIG. 4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SP_B
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22_2
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28_1,29_1
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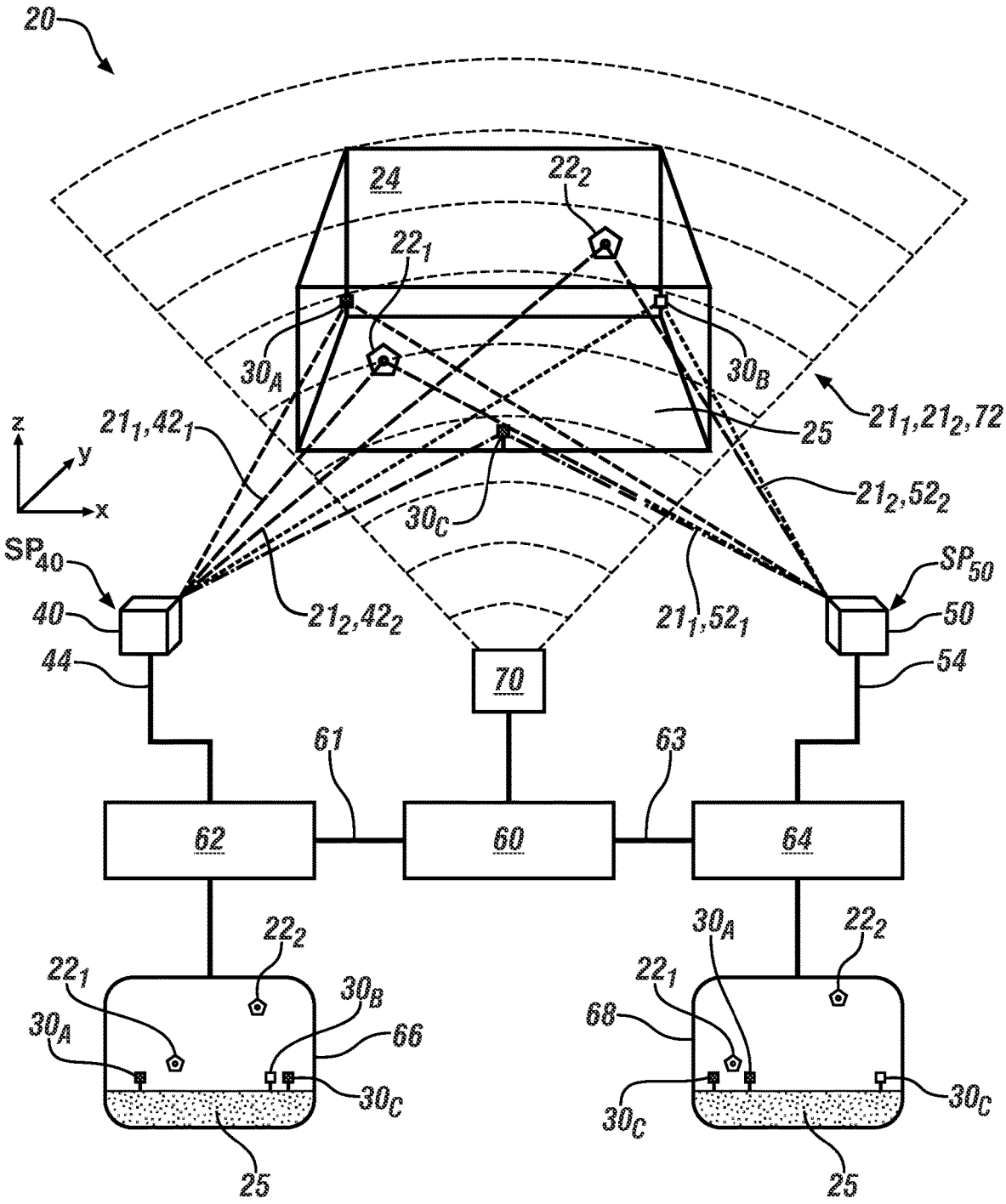
30_A
30_B
21_2,42_2
25
30_C
42_B
z
y
x
42_A
21_1,42_1
42_C
53_{TX2},53_{RX2},M_2
53_{TX1},53_{RX1},M_1
70
40
51
SP_{40}
SP_{51}
44
54
60,61,62,63,65
22_2
22_1
30_B
30_A
66
30_C
25
67
3714.2 ft
4960.7 ft

FIG. 5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24
22_2
22_1
30_A
30_B
30_C
$21_1,42_1$
$21_2,42_2$
$21_1,21_2,72$
25
$21_2,52_2$
$21_1,52_1$
z
y
x
SP_{40}
SP_{50}
40
50
44
54
70
61
63
62
60
64
66
68
25

FIG. 6

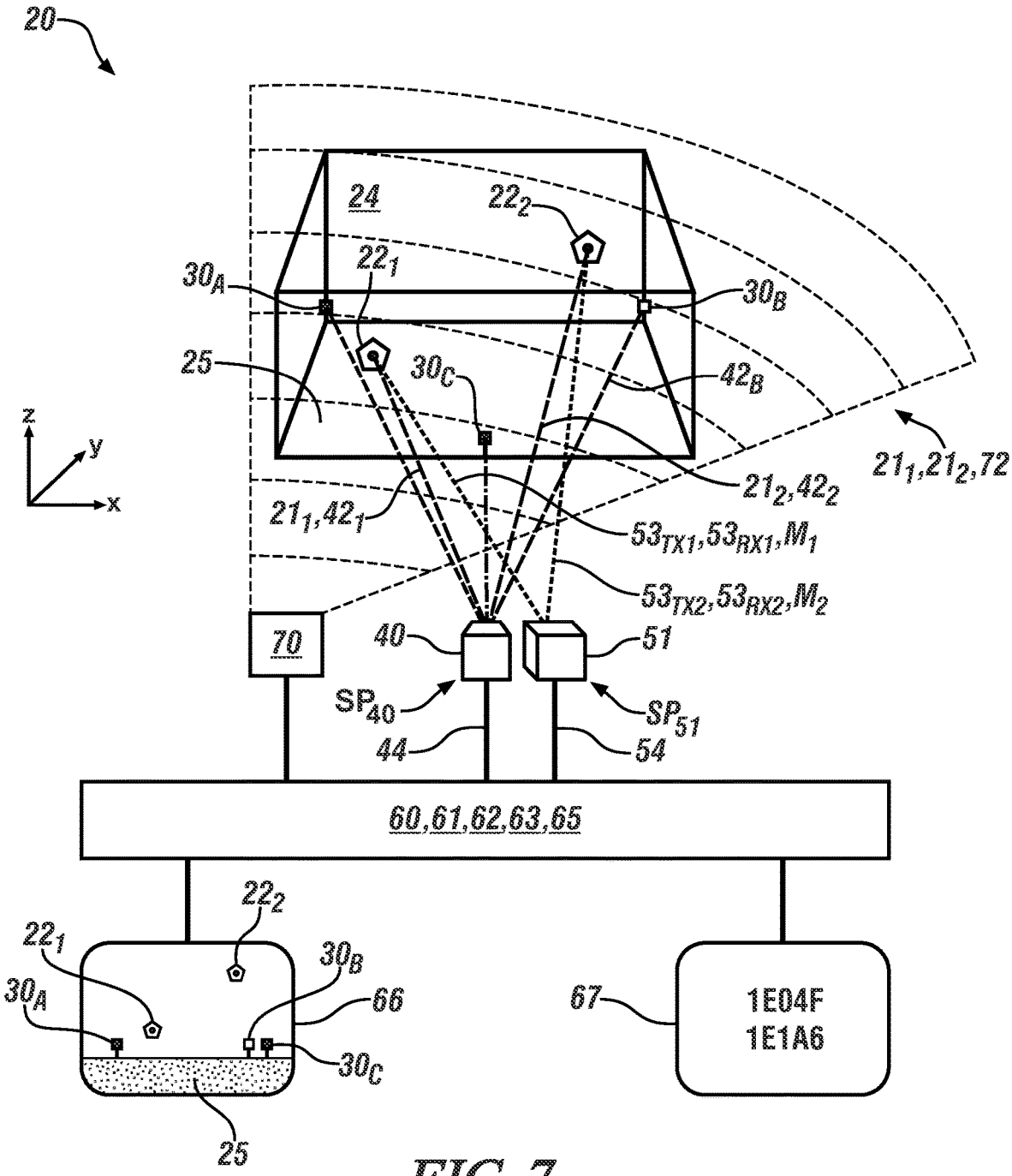
20
24
22_2
22_1
30_A
30_B
25
30_C
42_B
z
y
x
$21_1,21_2,72$
$21_2,42_2$
$21_1,42_1$
$53_{TX1},53_{RX1},M_1$
$53_{TX2},53_{RX2},M_2$
70
40
51
SP_{40}
SP_{51}
44
54
60,61,62,63,65
22_2
22_1
30_B
30_A
66
30_C
25
67
1E04F
1E1A6

FIG. 7

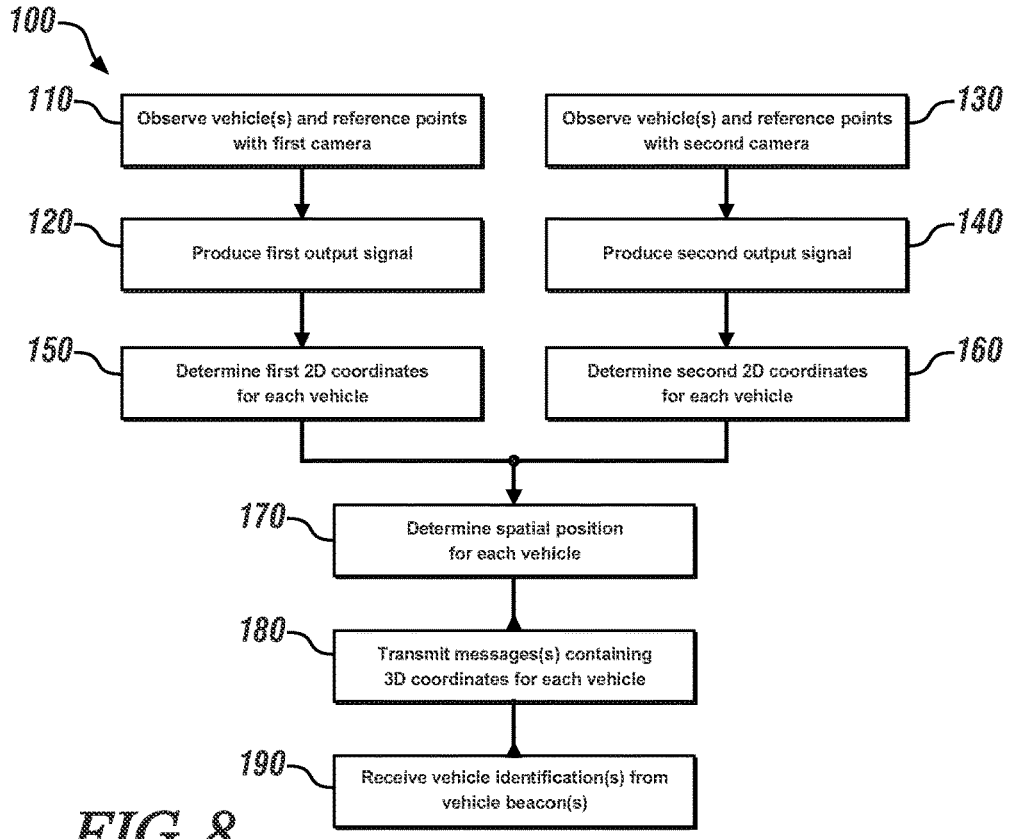
100
110
Observe vehicle(s) and reference points with first camera
120
Produce first output signal
150
Determine first 2D coordinates for each vehicle
130
Observe vehicle(s) and reference points with second camera
140
Produce second output signal
160
Determine second 2D coordinates for each vehicle
170
Determine spatial position for each vehicle
180
Transmit messages(s) containing 3D coordinates for each vehicle
190
Receive vehicle identification(s) from vehicle beacon(s)

FIG. 8

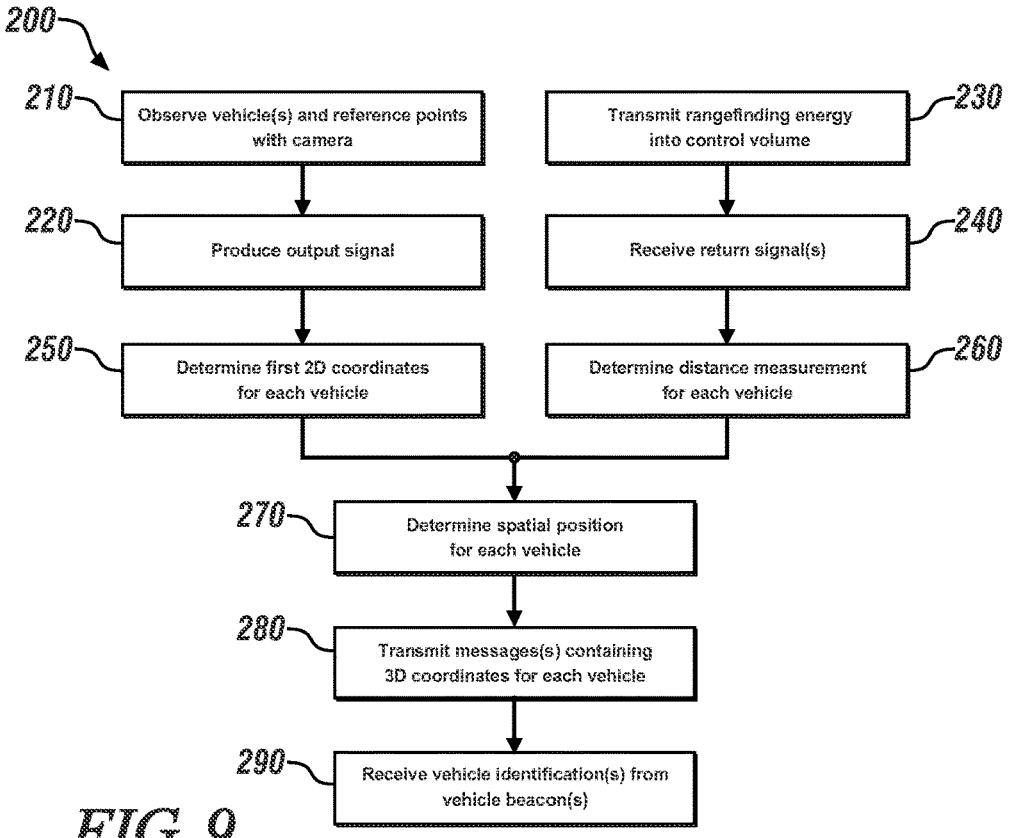
200
210
Observe vehicle(s) and reference points with camera
220
Produce output signal
250
Determine first 2D coordinates for each vehicle
230
Transmit rangefinding energy into control volume
240
Receive return signal(s)
260
Determine distance measurement for each vehicle
270
Determine spatial position for each vehicle
280
Transmit messages(s) containing 3D coordinates for each vehicle
290
Receive vehicle identification(s) from vehicle beacon(s)

FIG. 9

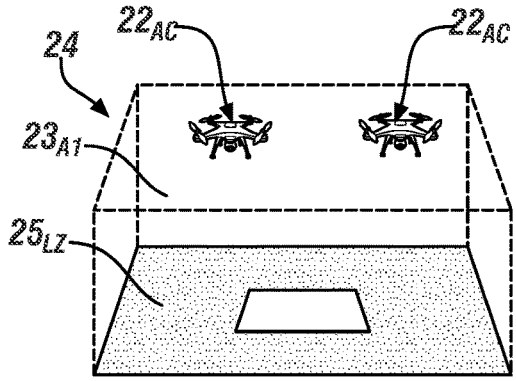

FIG. 10A

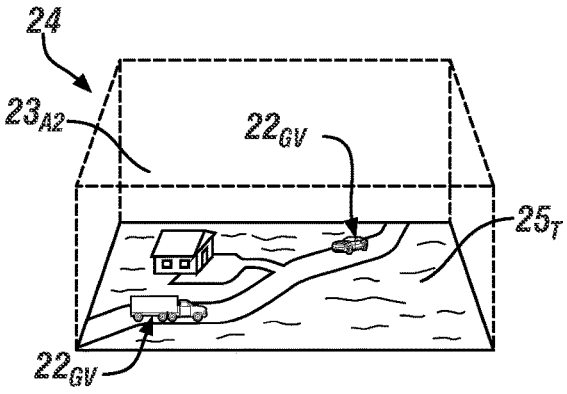

FIG. 10B

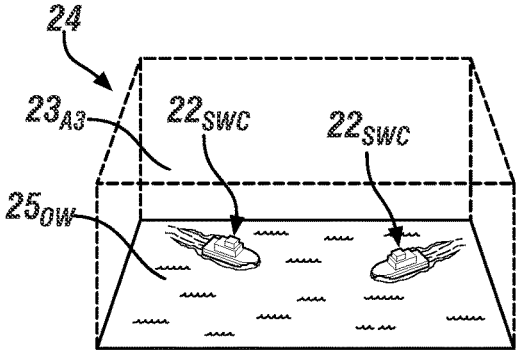

FIG. 10C

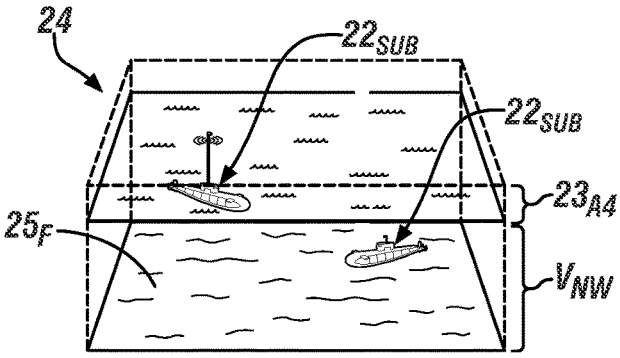

FIG. 10D

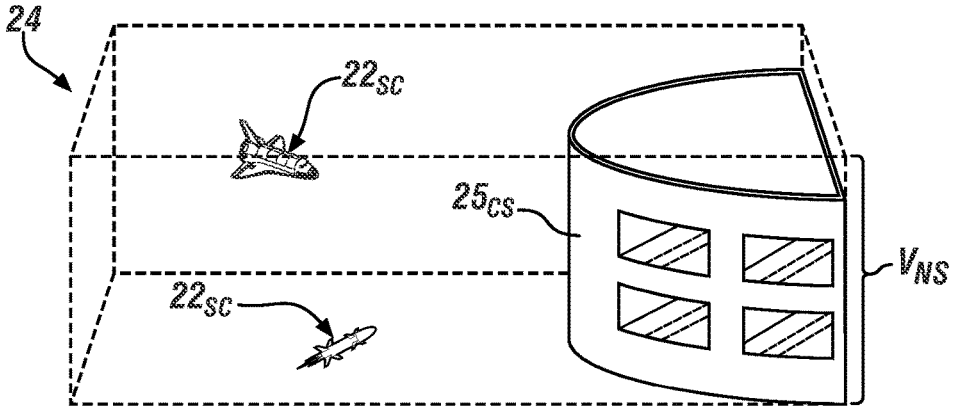

FIG. 10E

NAVIGATION SYSTEM AND METHOD

CROSS-REFERENCE RELATED APPLICATION

The present application claims priority to, and the benefit of, U.S. Provisional Patent Application No. 63/138,578 filed on Jan. 18, 2021, the entire disclosure of which is incorporated by reference herein.

INTRODUCTION

This disclosure relates generally to systems and methods of navigation for one or more vehicles located within a control volume.

Global positioning systems (GPS) may be used for navigation and geo-location in a wide variety of applications, including aircraft, surface watercraft, automotive vehicles and personal cell phones. However, GPS signals are not available or reliable in some environments, such as the "urban canyon" environments of large cities where tall buildings may obstruct GPS signals. GPS can also be electronically jammed, may not work reliably at high latitudes, and occasionally suffers drop-outs and periods of interrupted service.

Some alternatives to GPS systems are available, such as on-board radar, infrared camera systems and the like, but such alternatives tend to be heavy and expensive.

SUMMARY

According to one embodiment, a navigation system for one or more vehicles located within a control volume includes: a first camera configured to observe the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively, the first camera being further configured to produce a first output signal from observation of the observed vehicles and reference points; a second camera configured to observe the one or more vehicles and the first, second and third reference points within a second field of view, the second camera being further configured to produce a second output signal from observation of the observed vehicles and reference points; and a processor operatively connected with the first and second cameras and configured to determine a respective spatial position for each of the one or more vehicles from the first and second output signals.

Each of the first, second and third known spatial positions may be a respective set of x, y and z coordinates, and each of the first, second and third known spatial positions may be known with respect to an origin located within the control volume. Additionally, each of the first and second cameras may be configured to detect at least one of visible light, infrared light and ultraviolet light, and may be disposed such that their respective fields of view are generally orthogonal with each other. Further, each of the first, second and third reference points may be (i) a respective point on a respective physical object disposed within the control volume and/or (ii) a respective focal point of a respective reference point beacon disposed within the control volume.

The first output signal may be representative of a first two-dimensional image of the control volume as viewed from the first camera, and the second output signal may be representative of a second two-dimensional image of the control volume as viewed from the second camera.

The navigation system may further include: (i) a transmitter operatively connected with the processor and configured to transmit one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles; (ii) a first real-time tracking system operatively connected with the first camera for determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions, and a second real-time tracking system operatively connected with the second camera for determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions; and/or (iii) a respective vehicle beacon configured to be carried aboard each of the one or more vehicles, wherein each vehicle beacon is configured to transmit a respective vehicle identification.

The one or more vehicles and the control volume may be, respectively: one or more aircraft and a landing zone including a first airspace above the landing zone; one or more ground vehicles and an area of terrain including a second airspace above the terrain; one or more surface watercraft and a region of open water including a third airspace above the open water; one or more submersible watercraft and a volume of navigable water; or one or more spacecraft and a volume of navigable space.

According to another embodiment, a navigation system for one or more vehicles located within a control volume includes: (i) a first camera configured to observe the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively, and wherein each of the first, second and third known spatial positions is known with respect to an origin located within the control volume, the first camera being further configured to produce a first output signal from observation of the observed vehicles and reference points, wherein the first output signal is representative of a first two-dimensional image of the control volume as viewed from the first camera; (ii) a second camera configured to observe the one or more vehicles and the first, second and third reference points within a second field of view, the second camera being further configured to produce a second output signal from observation of the observed vehicles and reference points, wherein the second output signal is representative of a second two-dimensional image of the control volume as viewed from the second camera; (iii) a processor operatively connected with the first and second cameras and configured to determine a respective spatial position for each of the one or more vehicles from the first and second output signals; and (iv) a transmitter operatively connected with the processor and configured to transmit one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles.

Each of the first, second and third known spatial positions may be a respective set of x, y and z coordinates, and the first and second cameras may be disposed such that their respective fields of view are generally orthogonal with each other. Each of the first, second and third reference points may be (i) a respective point on a respective physical object disposed within the control volume and/or (ii) a respective focal point of a respective reference point beacon disposed within the control volume.

The navigation system may further include a respective vehicle beacon configured to be carried aboard each of the one or more vehicles, wherein each vehicle beacon is configured to transmit a respective vehicle identification.

Additionally, the navigation system may further include: a first real-time tracking system operatively connected with the first camera for determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions; and a second real-time tracking system operatively connected with the second camera for determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions.

According to yet another embodiment, a method of navigation for one or more vehicles located within a control volume includes: (i) observing, with a first camera, the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively; (ii) producing, by the first camera, a first output signal from observation of the observed vehicles and reference points; (iii) observing, with a second camera, the one or more vehicles and the first, second and third reference points within a second field of view; (iv) producing, by the second camera, a second output signal from observation of the observed vehicles and reference points; and (v) determining, by a processor operatively connected with the first and second cameras, a respective spatial position for each of the one or more vehicles from the first and second output signals.

The method may further include one or more of: determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions; determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions; transmitting one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles; and receiving a respective vehicle identification transmitted from a respective vehicle beacon carried aboard each of the one or more vehicles.

The above features and advantages, and other features and advantages, of the present teachings are readily apparent from the following detailed description of some of the best modes and other embodiments for carrying out the present teachings, as defined in the appended claims, when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front perspective schematic view and block diagram of first and second embodiments of a navigation system.

FIG. **2** is a perspective schematic view of a reference point beacon, emitter or reflector.

FIG. **3** is an alternative front perspective schematic view and block diagram of the configuration shown in FIG. **1**.

FIG. **4** is a front perspective schematic view and block diagram of third and fourth embodiments of a navigation system.

FIG. **5** is a front perspective schematic view and block diagram of an alternative configuration of the third and fourth embodiments.

FIG. **6** is another alternative front perspective schematic view and block diagram of the first configuration shown in FIGS. **1** and **3**, illustrating message broadcast.

FIG. **7** is an alternative front perspective schematic view and block diagram of the third configuration shown in FIG. **5**, illustrating message broadcast.

FIG. **8** is a flowchart for a method of navigation utilizing a navigation system according to first and second embodiments of the present disclosure.

FIG. **9** is a flowchart for a method of navigation utilizing a navigation system according to third and fourth embodiments of the present disclosure.

FIGS. **10**A-E are schematic perspective views of the vehicles and control volume of FIGS. **1** and **3-7**, specifically: aircraft and a landing zone; ground vehicles and an area of terrain; surface watercraft and a region of open water; submersible watercraft and a volume of navigable water; and spacecraft and a volume of navigable space.

DETAILED DESCRIPTION

Referring now to the drawings, wherein like numerals indicate like parts in the several views, a navigation system **20** for one or more vehicles **22** located within a control volume **24**, and a method **100**, **200** of navigation for one or more vehicles **22** located within a control volume **24**, are shown and described herein. The navigation system **20** and method **100**, **200** are described below in multiple embodiments, each of which is effective for determining the spatial position SP (e.g., three-dimensional spatial coordinates **69**) of each of the one or more vehicles **22** within the control volume **24**, which may be used for navigation, collision avoidance, trajectory planning, traffic control and the like.

The navigation system **20** and method **100**, **200** provide GPS-like navigation information which may be useful in environments where GPS is not available or not reliable (such as "urban canyon" environments in cities). Additionally or alternatively, the navigation system **20** and method **100**, **200** may serve as a complementary, supplemental or redundant back-up system to GPS and other geo-location systems.

Note that certain reference numerals in the drawings have subscripts, such as the two vehicles $\mathbf{22}_1$ and $\mathbf{22}_2$ in FIGS. **1** and **3-7**. Subscripts are used in the drawings and in the present description to refer to individual elements (such as the aforementioned vehicles), while the use of reference numerals without subscripts may refer to the collective group of such elements and/or to a singular but generic one of such elements. Thus, reference numeral $\mathbf{22}_1$ refers to a specific vehicle, while reference numeral **22** (without the subscript) may refer to all the vehicles, the group of vehicles, or a singular but generic vehicle (i.e., any vehicle).

The control volume **24** is represented in the drawings as a rectangular volume, but other volumetric shapes may also be used. Each of the vehicles **22** is represented in the drawings as a small pentagon having a center or centroid **28**, at which an optional time-modulated beacon or transponder **29** may be carried. (Such beacons **29** may also be carried at locations other than the vehicle centroid **28**, such as on the vehicle's exterior.) The vehicles **22** and control volume **24** are described herein in an exemplary manner as being, respectively, one or more aircraft (e.g., fixed-wing, rotary-wing, drones, etc.) $\mathbf{22}_{AC}$, and a landing zone or runway $\mathbf{25}_{LZ}$ including a first airspace $\mathbf{23}_{A1}$ above the landing zone $\mathbf{25}_{LZ}$ (FIG. **10**A). However, the one or more vehicles **22** and the control volume **24** may assume various other configurations, such as: (i) one or more ground vehicles $\mathbf{22}_{GV}$ and an area of terrain $\mathbf{25}_T$ including a second airspace $\mathbf{23}_{A2}$ above the terrain $\mathbf{25}_T$ (FIG. **10**B); (ii) one or more surface watercraft $\mathbf{22}_{SWC}$ and a region of open water having a surface $\mathbf{25}_{OW}$ and

including a third airspace 23_{A3} above the open water surface 25_{OW} (FIG. **10**C); (iii) one or more submersible watercraft 22_{SUB} and a volume of navigable water V_{NW}, optionally including an open water surface 25_{OW}, a fourth airspace 23_{A4} above the water surface 25_{OW}, and/or a sea floor, river bed or other ground plane 25_F beneath the volume of water V_{NW} (FIG. **10**D); or (iv) one or more satellite or other spacecraft 22_{SC} and a volume of navigable space V_{NS}, optionally including one or more control surfaces 25_{CS} (e.g., the outer surface of a space station, asteroid, etc.) which the spacecraft 22_{SC} may be engaged with (FIG. **10**E). Note that the drawings herein are schematic in nature and are not necessarily drawn to scale.

As illustrated in FIGS. **1**, **3-5** and **10**A-E, the control volume **24** may have a surface **25** therein, such as the ground (in the case of an airspace), the surface above a body of water, or a sea floor, river bed or the like beneath a volume of water. This surface **25** may be flat and smooth, or uneven and undulating. The control volume **24** may also contain an origin or zero point **26** from which position coordinates may be measured for vehicles **22** and other objects within the control volume **24**. The origin or zero point **26** may correspond to a physical landmark or other physical object within the control volume **24**, or it may be an arbitrarily assigned point in space within the control volume **24**. From this origin or zero point **26**, the respective x, y and z coordinates of other objects within the control volume **24** (e.g., vehicles **22** and reference points **30**) may be determined. For example, as illustrated in FIG. **1**, the origin **26** may be defined at the front lower left corner of the control volume **24**, with the x, y and z coordinates of a first vehicle 22_1 being (x_1, y_1, z_1) and of a second vehicle 22_2 being (x_2, y_2, z_2). As other examples, the origin **26** may be a landing point on the ground, a landing point on a building or other structure, a landing point on a vehicle **22**, a docking point or dock in a port, and the like. Thus, the origin **26** may be the intended destination or landing/docking point for one or more vehicles **22**, and the x, y and z axes and coordinates may be defined as extending from the origin **26**. Note that prior to implementation of the navigation system **20** and method **100**, **200**, the x, y and z coordinates of the one or more of the vehicles **22**—and perhaps of all of the vehicles **22**—are not known, but may be determined by use of the navigation system **20** and method **100**, **200**.

The control volume **24** may also contain first and second reference points 30_A, 30_B, and optionally a third reference point 30_C. (Alternatively, one or more of these reference points **30** may be disposed outside of the control volume **24**, as further discussed below.) Each of these reference points 30_A, 30_B, 30_C has a respective known spatial position SP_A, SP_B, SP_C, each of which may be represented by a respective set of x, y and z coordinates (e.g., as measured from or defined with respect to the origin **26**). Each of the first, second and third known spatial positions SP_A, SP_B, SP_C may be known, measured or defined with respect to the origin **26**, which may be located within the control volume **24** or outside the control volume **24**. For example, as shown in FIG. **1**, the first and second reference points 30_A, 30_B may be located at the two back lower corners of the control volume **24**, and the third reference point 30_C may be located in the middle of the front lower edge of the control volume **24**, with all three reference points 30_A, 30_B, 30_C being elevated just slightly above the surface or ground **25**. Each of the reference points 30_A, 30_B, 30_C may be (i) a respective point **31** on a respective physical object **39** disposed within the control volume **24**, and/or (ii) a respective focal point **38** of a respective reference point beacon **32** disposed within the control volume **24**. The known spatial positions SP_A, SP_B, SP_C of the reference points 30_A, 30_B, 30_C may be known, measured or defined relative to an Earth-oriented inertial reference frame, or to any arbitrary inertial reference frame, which may be stationary with respect to the Earth (such as a helipad on the roof of a building) or moving (such as a helipad on a boat floating/moving on the surface of a body of water).

FIG. **2** shows a perspective schematic view of a reference point beacon, emitter or reflector **32** (hereinafter referred to as a "beacon/reflector") which may be used for each reference point **30**. The beacon/reflector **32** includes body portion **33** carried atop a stand **34** which is fixed in the ground or surface **25**, thus disposing the body portion **33** at a certain height above the surface **25**. (Alternatively, the beacon/reflector **32** may not include a stand **34**, and the body portion **33** may be disposed upon or flush with the ground surface **25**.) The beacon/reflector **32** may be an "active" device which includes a lens or emitter portion **35** on the body portion **33** from which a collection of beams or rays of electromagnetic (EM) energy **36** may be directed (such as visible light, microwave energy, etc.). In the case of an active beacon/reflector **32**, the EM energy **36** may be emanating continuously or in pulses. On the other hand, the beacon/reflector **32** may be a "passive" device which includes a mirror or reflector portion **35** on the body portion **33** which easily reflects EM energy **36**. The lens/emitter portion/mirror/reflector portion **35** may be configured such that the rays of emanated or reflected EM energy **36** may be characterized by a central axis, beam or ray **37** extending from a focal point **38** centrally located on the lens/emitter portion/mirror/reflector portion **35**. Alternatively, the beacon/reflector **32** may be an ordinary physical object **39** (e.g., a boulder, sign or landmark) which is disposed within (or even outside of) the control volume **24** and which may serve as a convenient reference point **30**. In any case, a particular point **31** on the beacon/reflector **32** may be used as the specific and precise location of the reference point **30**.

FIG. **1** illustrates a first embodiment of the navigation system **20** for one or more vehicles **22** located within a control volume **24**. The navigation system **20** includes a first camera or receiver **40** configured to observe the one or more vehicles **22** and the first, second and third reference points 30_A, 30_B, 30_C within a first field of view **45**, wherein the first, second and third reference points 30_A, 30_B, 30_C have first, second and third known spatial positions SP_A, SP_B, SP_C, respectively. The first camera **40** is further configured to produce a first output signal **44** from observation of the observed vehicles **22** and reference points **30**. The navigation system **20** also includes a second camera or receiver **50** configured to observe the vehicles **22** and reference points **30** within a second field of view **55**, with the second camera **50** being further configured to produce a second output signal **54** from observation of the observed vehicles **22** and reference points **30**. (For example, the first and second output signals **44**, **54** may comprise video signals, a stream of still images, or the like.) Additionally, the navigation system **20** includes a processor **60** operatively connected with the first and second cameras **40**, **50** and configured to determine a respective spatial position SP for each of the one or more vehicles **22** from the first and second output signals **44**, **54**. Thus, for example, if there are two vehicles 22_1, 22_2 being viewed by the first and second cameras **40**, **50**, then the processor **60** will determine respective spatial positions SP_1, SP_2 for the vehicles 22_1, 22_2. Each of these spatial positions SP_1, SP_2 may be represented by a respective set of

three-dimensional coordinates $\mathbf{69}_1$, $\mathbf{69}_2$ such as x, y and z (or other) coordinates (e.g., as measured from the origin **26**).

Each of the first and second cameras/receivers **40**, **50** may be configured to detect or receive visible light, infrared light and/or ultraviolet light, as well as other wavelengths of EM energy **26** (e.g., microwaves). The first camera **40** is configured to detect first EM signals **42** within a first collection volume or field of view **45** having a first central ray or path **46**, and the second camera **50** is configured to detect second EM signals **52** within a second collection volume or field of view **55** having a second central ray or path **56**. The first collection volume or field of view **45** may have opposed first and second lateral edges **47**, **48** and a distal extent or edge **49**, which may be envisioned as somewhat of a wedge or cone shape. Likewise, the second collection volume or field of view **55** may have opposed first and second lateral edges **57**, **58** and a distal extent or edge **59**, which may also be envisioned as somewhat of a wedge or cone shape. However, these shapes are merely illustrative, as the first and second fields of view **45**, **55** may also assume other shapes.

Each of the first and second cameras/receivers **40**, **50** is configured and/or positioned to view the control volume **24** within its respective field of view **45**, **55**, as well as the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$. While the drawings illustrate the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ as being inside of or at the outer boundary of the control volume **24**, one or more of these reference points **30** may be disposed outside of the control volume **24**. For example, the third reference point $\mathbf{30}_C$ may be disposed near the location illustrated in FIGS. **1** and **3-7**, but slightly outside the control volume **24** and slightly closer to the cameras **40**, **50** than is illustrated in the aforementioned drawings. (I.e., the third reference point $\mathbf{30}_C$ would be disposed slightly "in front of" the control volume **24**.) In this example, the third reference point $\mathbf{30}_C$ would still be seen within each of the two fields of view **45**, **55**. Likewise, one or both of the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ may be disposed near their respective locations illustrated in FIGS. **1** and **3-7**, but slightly outside of and "behind" the control volume **24**, and in this case, too, the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ would still be visible within each of the two fields of view **45**, **55**.

Note that the word "receiver", as used herein, includes any device configured to receive EM energy **26** from the control volume **24** and produce an electrical signal (e.g., output signals **44** and **54**) that is representative of or provides spatial/locational information about objects disposed within the control volume **24**. Thus, "receiver" include devices such as (i) cameras and imagers which are configured to form images of the objects within the control volume **24** (whether using visible light or EM energy **26** of other wavelengths), as well as (ii) rangefinders and the like which are configured to measure the distance to objects by transmitting or directing EM energy **26** (or other energy, such as sonar) at each object and receiving EM energy **26** (or other energy) in the form of a return signal back from each object. In the first and second embodiments, two cameras **40**, **50** are utilized, which may provide, simulate or enable a binocular or stereoscopic view of the control volume **24**.

As illustrated in FIGS. **1**, **3** and **6**, the first and second cameras **40**, **50** may be disposed such that their respective collection volumes or fields of view **45**, **55** are generally orthogonal with each other, with the first and second central rays **46**, **56** meeting at a convergence point **27** and with an angle θ defined between the first and second central rays **46**, **56** of approximately 90 degrees. The first EM signals **42** (which are detected by the first camera **40**) are illustrated in FIGS. **1** and **3-7** as signals $\mathbf{42}_1$, $\mathbf{42}_2$ coming from the first and second vehicles $\mathbf{22}_1$, $\mathbf{22}_2$, and signals $\mathbf{42}_A$, $\mathbf{42}_B$, $\mathbf{42}_C$ coming from the first, second and third reference points or beacon/emitters $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$. Similarly, the second EM signals **52** (which are detected by the second camera **50**) are illustrated as signals $\mathbf{52}_1$, $\mathbf{52}_2$ coming from the first and second vehicles $\mathbf{22}_1$, $\mathbf{22}_2$, and signals $\mathbf{52}_A$, $\mathbf{52}_B$, $\mathbf{52}_C$ coming from the first, second and third reference points or beacon/emitters $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$. Note that while the first and second cameras **40**, **50** and reference points **30** are depicted in the drawings as being fixed, one or more of these elements may be gimbaled for rotation about one or more axes, and/or configured for translation or other motions.

The first output signal **44** may be representative of a first two-dimensional image **66** of the control volume **24** as viewed from the first camera **40**, and the second output signal **54** may be representative of a second two-dimensional image **68** of the control volume **24** as viewed from the second camera **50**. These images **66**, **68** may be viewed together or separately on one or more monitors or other display devices, which may be connected to the processor **60**, the cameras **40**, **50**, or the real-time tracking systems **62**, **64** described below.

The navigation system **20** may further include (i) a first real-time tracking system **62** operatively connected with the first camera **40** for determining respective first two-dimensional coordinates **61** for each of the one or more vehicles **22** using the first output signal **44** and the first, second and third known spatial positions SP_A, SP_B, SP_C, and (ii) a second real-time tracking system **64** operatively connected with the second camera **50** for determining respective second two-dimensional coordinates **63** for each of the one or more vehicles **22** using the second output signal **54** and the first, second and third known spatial positions SP_A, SP_B, SP_C. Note that while the processor **60** and the real-time tracking systems **62**, **64** are shown in FIGS. **1**, **3-4** and **6** as being separate modules or elements, the functionality of the real-time tracking systems **62**, **64** may be included as part of the processor **60**, as illustrated in FIGS. **5** and **7**.

The navigation system **20** may further include a respective vehicle beacon or transponder **29** configured to be carried aboard each of the one or more vehicles **22**. Each vehicle beacon **29** may be configured to transmit or broadcast a respective vehicle identification **21**, utilizing the same range of EM energy **26** which the first and second cameras **40**, **50** are configured to receive. For example, a vehicle beacon $\mathbf{29}_1$ carried aboard a first vehicle $\mathbf{22}_1$ (e.g., at the first vehicle's centroid $\mathbf{28}_1$, outer surface, etc.) may emit a first vehicle identification $\mathbf{21}_1$ as a series of long and short intermittent pulses of light which serve to identify the first vehicle $\mathbf{22}_1$, while a vehicle beacon $\mathbf{29}_2$ carried aboard a second vehicle $\mathbf{22}_2$ (e.g., at the second vehicle's centroid $\mathbf{28}_2$, outer surface, etc.) may emit a second vehicle identification $\mathbf{21}_2$ that is different from the first vehicle identification $\mathbf{21}_1$ (and is unique to the second vehicle $\mathbf{22}_2$) in order to identify the second vehicle $\mathbf{22}_2$. (These pulses may be in Morse code, binary code or other format.) Optionally, the pulses of the vehicle beacon **29** may be at a wavelength just outside the visible spectrum (e.g., infrared or ultraviolet), and the cameras **40**, **50** may be configured to detect this wavelength in addition to the visible spectrum.

Additionally, the navigation system **20** may further include a transmitter **70** operatively connected with the processor **60** and configured to transmit or broadcast one or more messages **72** into the control volume **24**, wherein the one or more messages **72** contain a respective spatial posi-

tion SP or set of three-dimensional spatial coordinates **69** for each of the vehicles **22** that are within the control volume **24**. Thus, the transmitter **70** is configured to broadcast the exact spatial location of each and every vehicle **22** within the control volume **24**. (This information may then be received and used by each vehicle **22**, and/or by a traffic control function, in order to assist in navigation, collision avoidance, trajectory planning, traffic control and the like.) These spatial positions SP or three-dimensional spatial coordinates **69** may be expressed as x, y and z coordinates, polar coordinates, or other coordinates, and may utilize the origin **26** or other point as the coordinate origin.

In addition to including the spatial positions SP or three-dimensional spatial coordinates **69** of all the vehicles **22** within the control volume **24**, the one or more messages **72** may also include the vehicle identifications **21** for all the vehicles **22**. The one or more messages **72** may be sequenced and/or structured such that each vehicle identification **21** may be readily associated with its corresponding vehicle's spatial position SP or three-dimensional spatial coordinates **69**. (Note that as used herein, spatial position SP and three-dimensional spatial coordinates **69** may be used interchangeably.) For example, either or both of the first and second cameras **40**, **50** may receive a first vehicle identification $\mathbf{21}_1$ from a first vehicle $\mathbf{22}_1$, a second vehicle identification $\mathbf{21}_2$ from a second vehicle $\mathbf{22}_2$, and so forth, and the transmitter **70** may transmit one or more messages **72** collectively containing all the vehicle identifications ($\mathbf{21}_1$, $\mathbf{21}_2$, etc.) and all the vehicles' spatial locations (SP_1, SP_2, etc.) or three-dimensional spatial coordinates ($\mathbf{69}_1$, $\mathbf{69}_2$, etc.) in a manner in which the unique spatial locations SP or three-dimensional spatial coordinates **69** are appropriately associated with their respective vehicle identifications **21**.

According to another configuration, a navigation system **20** for one or more vehicles **22** located within a control volume **24** includes: (i) a first camera **40** configured to observe the one or more vehicles **22** and first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ within a first field of view **45**, wherein the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ have first, second and third known spatial positions SP_A, SP_B, SP_C, respectively, and wherein each of the first, second and third known spatial positions $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ is known with respect to an origin **26** located within the control volume **24**, the first camera **40** being further configured to produce a first output signal **44** from the observed vehicles **22** and reference points **30**, wherein the first output signal **44** is representative of a first two-dimensional image **66** of the control volume **24** as viewed from the first camera **40**; (ii) a second camera **50** configured to observe the one or more vehicles **22** and the first, second and third reference points, $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ within a second field of view **55**, the second camera **50** being further configured to produce a second output signal **54** from the observed vehicles **22** and reference points **30**, wherein the second output signal **54** is representative of a second two-dimensional image **68** of the control volume **24** as viewed from the second camera **50**; (iii) a processor **60** operatively connected with the first and second cameras **40**, **50** and configured to determine a respective spatial position SP for each of the one or more vehicles **22** from the first and second output signals **44**, **54**; and (iv) a transmitter **70** operatively connected with the processor **60** and configured to transmit one or more messages **72** into the control volume **24**, wherein the one or more messages **72** contain a respective set of three-dimensional spatial coordinates **69** for each of the one or more vehicles **22**.

As illustrated by the flowchart of FIG. **8**, a method **100** of navigation for one or more vehicles **22** located within a control volume **24** is also provided. At step **110**, the one or more vehicles **22** are observed with a first camera **40**, along with first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$, within a first field of view **45**, wherein the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ have first, second and third known spatial positions SP_A, SP_B, SP_C, respectively. At step **120**, a first output signal **44** is produced by the first camera **40** from the observed vehicles **22** and reference points **30**. At step **130**, the one or more vehicles **22** and the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ are observed within a second field of view **55** with a second camera **50**. At step **140**, a second output signal **54** from the observed vehicles **22** and reference points **30** is produced by the second camera **50**. And at step **170**, a respective three-dimensional spatial position SP for each vehicle **22** is determined, from the first and second output signals **44**, **54**, by a processor **60** operatively connected with the first and second cameras **40**, **50**.

The method **100** of navigation may further include one or more additional steps. For example, at step **150**, respective first two-dimensional coordinates **61** may be determined for each of the one or more vehicles **22** using the first output signal **44** and the first, second and third known spatial positions SP_A, SP_B, SP_C, and similarly at step **160**, respective second two-dimensional coordinates **63** may be determined for each vehicle **22** using the second output signal **54** and the first, second and third known spatial positions SP_A, SP_B, SP_C. At step **180**, one or more messages **72** may be transmitted into the control volume **24**, wherein the one or more messages **72** contain a respective set of three-dimensional spatial coordinates **69** for each vehicle **22**. And at step **190**, a respective vehicle identification **21** may be received (e.g., by the first and/or second camera **40**, **50**), which is transmitted from a respective vehicle beacon or transponder **29** carried aboard each of the one or more vehicles **22**.

In addition to the first embodiment illustrated in FIGS. **1**, **3** and **6** in which two cameras **40**, **50** and three reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ having known spatial positions SP_A, SP_B, SP_C are used, the navigation system **20** and method **100** may also include three other different but related embodiments. These include: (i) a second embodiment in which two cameras **40**, **50** and two reference points $\mathbf{30}_A$, $\mathbf{30}_B$ having known spatial positions SP_A, SP_B are used, along with known first and second spatial positions SP_{40}, SP_{50} for the cameras **40**, **50**; (ii) a third embodiment in which one camera **40**, one transceiver **51** and three reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ having known spatial positions SP_A, SP_B, SP_C are used; and (iii) a fourth embodiment in which one camera **40**, one transceiver **51** and two reference points $\mathbf{30}_A$, $\mathbf{30}_B$ having known spatial positions SP_A, SP_B are used, along with known first and second spatial positions SP_{40}, SP_{51} for the camera **40** and transceiver **51**. These four embodiments are summarized below in TABLE 1.

TABLE 1

Comparison of Embodiments

Embodiment	First Receiver	Second Receiver	Known Spatial Positions: Reference Points	Known Spatial Positions: Receivers	Related Drawings: Navigation System 20	Related Drawings: Method 100, 200
First	Camera 40	Camera 50	SP_A, SP_B, SP_C	—	FIGS. 1, 3, 6	FIG. 8
Second	Camera 40	Camera 50	SP_A, SP_B	SP_{40}, SP_{50}	FIGS. 1, 3, 6	FIG. 8
Third	Camera 40	Transceiver 51	SP_A, SP_B, SP_C	—	FIGS. 4, 5, 7	FIG. 9
Fourth	Camera 40	Transceiver 51	SP_A, SP_B	SP_{40}, SP_{51}	FIGS. 4, 5, 7	FIG. 9

As used herein, a transceiver **51** is configured to both (i) transmit EM/rangefinding energy $\mathbf{53}_{TX}$ and (ii) receive EM/rangefinding energy $\mathbf{53}_{RX}$ in the form of a return signal reflected or evinced from other objects in the control volume **24** (such as vehicles **22**). For example, the transceiver **51** and the transmitted EM/rangefinding energy $\mathbf{53}_{RX}$ may be, respectively: a distance measuring equipment (DME) device and radio waves, a radar device and radar waves, a sonar device and sonar waves, or a laser rangefinder and coherent laser light. Note that the received EM energy/return signal $\mathbf{53}_{RX}$ may have the same wavelength as the transmitted EM energy $\mathbf{53}_{TX}$, or it may have a different wavelength. In the third and fourth embodiments, the transceiver **51** may be manually or automatedly directed at each vehicle **22** within the control volume **24** in order to determine or "range find" a distance M from the transceiver **51** to each vehicle **22**. For example, M_1 and M_2 are shown in the drawings to represent the respective distances from the transceiver **51** to the first and second vehicles $\mathbf{22}_1$, $\mathbf{22}_2$. A first beam of EM energy $\mathbf{53}_{TX1}$ may be directed at a first vehicle $\mathbf{22}_1$ and a return signal of EM energy $\mathbf{52}_{RX1}$ received back from the vehicle $\mathbf{22}_1$ by the transceiver **51**; then, a second beam of EM energy $\mathbf{53}_{TX2}$ may be directed at a second vehicle $\mathbf{22}_2$ and a return signal of EM energy $\mathbf{52}_{RX2}$ received back from the vehicle $\mathbf{22}_2$ by the transceiver **51**.

Note that the transceiver **51** does not necessarily have to transmit and receive EM energy $\mathbf{53}_{TX}$, $\mathbf{53}_{RX}$ from the very same device, but may include a transmitting portion and a receiving portion that are partially or entirely separate from each other, but which together comprise a transceiver **51**. The transceiver **51** may be configured to use the transmitted and received EM energy $\mathbf{53}_{TX}$, $\mathbf{53}_{RX}$ to determine the distance M from the transceiver **51** to targeted objects (such as each vehicle **22**), or the transceiver **51** may communicate with another device external to the transceiver **51**, such as a distance determination system or device **65**, which utilizes signals from the transceiver **51** to calculate or determine the distance M.

In the second embodiment, two cameras **40**, **50** and two reference points $\mathbf{30}_A$, $\mathbf{30}_B$ having known spatial positions SP_A, SP_B are used, along with known first and second spatial positions SP_{40}, SP_{50} for the cameras **40**, **50**. In this embodiment, as illustrated in FIGS. **1**, **3** and **6**, a navigation system **20** for one or more vehicles **22** located within a control volume **24** includes: a first camera **40** configured to observe the one or more vehicles **22** and first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within a first field of view **45**, wherein the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ have first and second known spatial positions SP_A, SP_B, respectively, the first camera **40** having a known first camera spatial position SP_{40} and being further configured to produce a first output signal **44** from the observed vehicles **22** and reference points **30**; a second camera **50** configured to observe the one or more vehicles **22** and the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within a second field of view **55**, the second camera **50** having a known second camera spatial position SP_{50} and being further configured to produce a second output signal **54** from the observed vehicles **22** and reference points **30**; and a processor **60** operatively connected with the first and second cameras **40**, **50** and configured to determine a respective spatial position SP for each of the one or more vehicles **22** from the first and second output signals **44**, **54** and from the known first and second camera spatial positions SP_{40}, SP_{50}.

In this second embodiment, each of the known first and second camera spatial positions SP_{40}, SP_{50} may be a respective set of x, y and z coordinates. The navigation system **20** may further include: (i) a first real-time tracking system **62** operatively connected with the first camera **40** for determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the first output signal **44**, the first and second known spatial positions SP_A, SP_B, and the known first camera spatial position SP_{40}; and (ii) a second real-time tracking system **64** operatively connected with the second camera **50** for determining respective second two-dimensional coordinates **63** of each of the one or more vehicles **22** using the second output signal **54**, the first and second known spatial positions SP_A, SP_B, and the known second camera spatial position SP_{50}. This second embodiment may also include any of the relevant subject matter of dependent claims **2-7** and **9-10** as originally filed.

As illustrated in FIG. **8**, in this second embodiment, a method **100** of navigation for one or more vehicles **22** located within the control volume **24** includes: (i) at step **110**, observing, with a first camera **40** having a known first camera spatial position SP_{40}, the one or more vehicles **22** and first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within the first field of view **45**, wherein the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ have first and second known spatial positions SP_A, SP_B, respectively; (ii) at step **120**, producing, by the first camera **40**, a first output signal **44** from the observed vehicles **22** and reference points **30**; (iii) at step **130**, observing, with a second camera **50** having a known second camera spatial position SP_{50}, the one or more vehicles **22** and the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within the second field of view **55**; (iv) at step **140**, producing, by the second camera **50**, a second output signal **54** from the observed vehicles **22** and reference points **30**; and (v) at step **170**, determining, by a processor **60** operatively connected with the first and second cameras **40**, **50**, a respective spatial position SP for each of the one or more vehicles **22** from the first and second output signals **44**, **54** and from the known first and second camera spatial positions SP_{40}, SP_{50}.

The method **100** of the second embodiment may further include one or more of: (vi) at step **150**, determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the first output signal **44**, the first and second known spatial positions SP_A, SP_B, and

the known first camera spatial position SP_{40}; (vii) at step **160**, determining respective second two-dimensional coordinates **63** of each of the one or more vehicles **22** using the second output signal **54**, the first and second known spatial positions SP_A, SP_B, and the known second camera spatial position SP_{50}; (viii) at step **180**, transmitting one or more messages **72** into the control volume **24**, wherein the one or more messages **72** contain a respective set of three-dimensional spatial coordinates **69** for each of the one or more vehicles **22**; and (ix) at step **190**, receiving a respective vehicle identification **21** transmitted from a respective vehicle beacon **29** carried aboard each of the one or more vehicles **22**.

In the third embodiment, one camera **40**, one transceiver **51** and three reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ having known spatial positions SP_A, SP_B, SP_C are used. In this embodiment, as illustrated in FIGS. **4**, **5** and **7**, a navigation system **20** for one or more vehicles **22** located within a control volume **24** includes: a camera **40** configured to observe the one or more vehicles **22** and first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ within a first field of view **45**, wherein the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ have first, second and third known spatial positions SP_A, SP_B, SP_C, respectively, the camera **40** being further configured to produce an output signal **44** from the observed vehicles **22** and reference points **30**; a transceiver **51** configured to transmit rangefinding energy $\mathbf{53}_{TX}$ into the control volume **24** and to receive a respective return signal $\mathbf{53}_{RX}$ from each of the one or more vehicles **22** indicative of a respective distance measurement M from the transceiver **51** to each respective vehicle **22**; and a processor **60** operatively connected with the camera **40** and transceiver **51** and configured to determine a respective spatial position SP for each of the one or more vehicles **22** from the output signal **44** and from at least one of the respective return signal $\mathbf{53}_{RX}$ and the respective distance measurement M.

In this third embodiment, the output signal **44** may be representative of a two-dimensional image **66** of the control volume **24** as viewed from the camera **40**. As illustrated in FIGS. **5** and **7**, the camera **40** and transceiver **51** may be disposed generally side-by-side with each other, such that a central ray **46** of the field of view **45** of the camera **40** and the one or more beams of EM energy $\mathbf{53}_{TX}$, $\mathbf{53}_{RX}$ of the transceiver **51** are generally pointing in the same direction as each other. (Here, "side-by-side" also includes the camera **40** and transceiver **51** being at different heights from each such, such as the transceiver **51** being disposed above or below the camera **40**.) The navigation system **20** may further include: (i) a real-time tracking system **62** operatively connected with the camera **40** for determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the output signal **44** and the first, second and third known spatial positions SP_A, SP_B, SP_C; and/or (ii) a distance determination system **65** operatively connected with the transceiver **51** for determining a respective distance M from the transceiver **51** to each of the one or more vehicles **22** using the respective return signals $\mathbf{53}_{RX}$ from each of the one or more vehicles **22**. This third embodiment may also include any of the relevant subject matter of dependent claims **2**, **5**, **7** and **9-10** as originally filed.

As illustrated in FIG. **9**, in this third embodiment, a method **200** of navigation for one or more vehicles **22** located within the control volume **24** includes: (i) at step **210**, observing, with a camera **40**, the one or more vehicles **22** and first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ within a first field of view, wherein the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$ have first, second and third known spatial positions SP_A, SP_B, SP_C, respectively; (ii) at step **220**, producing, by the camera **40**, an output signal **44** from the observed vehicles **22** and reference points **30**; (iii) at step **230**, transmitting, by a transceiver **51**, rangefinding energy $\mathbf{53}_{TX}$ into the control volume **24** (e.g., at each of the one or more vehicles **22**); (iv) at step **240**, receiving, by the transceiver **51**, a respective return signal $\mathbf{53}_{RX}$ from each of the one or more vehicles **22** indicative of a respective distance measurement M from the transceiver **51** to each respective vehicle **22**; and; (v) at step **270**, determining, by a processor **60** operatively connected with the camera **40** and transceiver **51**, a respective spatial position SP for each of the one or more vehicles **22** from the output signal **44** and from at least one of the respective return signal $\mathbf{53}_{RX}$ and the respective distance measurement M.

The method **200** of the third embodiment may further include one or more of: (vi) at step **250**, determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the output signal **44** and the first, second and third known spatial positions SP_A, SP_B, SP_C; (vii) at step **260**, determining a distance measurement M from the transceiver **51** to each of the one or more vehicles **22** using the respective return signals $\mathbf{53}_{RX}$; (viii) at step **280**, transmitting one or more messages **72** into the control volume **24**, wherein the one or more messages **72** contain a respective set of three-dimensional spatial coordinates **69** for each of the one or more vehicles **22**; and (ix) at step **290**, receiving a respective vehicle identification **21** transmitted from a respective vehicle beacon **29** carried aboard each of the one or more vehicles **22**.

In the fourth embodiment, one camera **40**, one transceiver **51** and two reference points $\mathbf{30}_A$, $\mathbf{30}_B$ having known spatial positions SP_A, SP_B are used, along with known first and second spatial positions SP_{40}, SP_{51} for the camera **40** and transceiver **51**. In this embodiment, as illustrated in FIGS. **4**, **5** and **7**, a navigation system **20** for one or more vehicles **22** located within a control volume **24** includes: a camera **40** configured to observe the one or more vehicles **22** and first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within a first field of view **45**, wherein the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ have first and second known spatial positions, SP_A, SP_B, respectively, the camera **40** having a known camera spatial position SP_{40} and being further configured to produce an output signal **44** from the observed vehicles **22** and reference points **30**; a transceiver **51** having a known transceiver spatial position SP_{51} and being configured to transmit rangefinding energy $\mathbf{53}_{TX}$ into the control volume **24** and to receive a respective return signal $\mathbf{53}_{RX}$ from each of the one or more vehicles **22** indicative of a respective distance measurement M from the transceiver **51** to each respective vehicle **22**; and a processor **60** operatively connected with the camera **40** and transceiver **51** and configured to determine a respective spatial position SP for each of the one or more vehicles **22** from (i) the output signal **44**, (ii) at least one of the respective return signal $\mathbf{53}_{RX}$ and the respective distance measurement M, and (iii) the known camera and transceiver spatial positions SP_{40}, SP_{51}.

In this fourth embodiment (and similar to the third embodiment), the output signal **44** may be representative of a two-dimensional image **66** of the control volume **24** as viewed from the camera **40**. As illustrated in FIGS. **5** and **7**, the camera **40** and transceiver **51** may be disposed generally side-by-side with each other, such that a central ray **46** of the field of view **45** of the camera **40** and the one or more beams of EM energy $\mathbf{53}_{TX}$, $\mathbf{53}_{RX}$ of the transceiver **51** are generally pointing in the same direction as each other. (Here, "side-by-side" also includes the camera **40** and transceiver **51**

being at different heights from each such, such as the transceiver **51** being disposed above or below the camera **40**.) The navigation system **20** may further include: (i) a real-time tracking system **62** operatively connected with the camera **40** for determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the output signal **44** and the first, second and third known spatial positions SP_A, SP_B, SP_C; and/or (ii) a distance determination system **65** operatively connected with the transceiver **51** for determining a respective distance M from the transceiver **51** to each of the one or more vehicles **22** using the respective return signals $\mathbf{53}_{RX}$ from each of the one or more vehicles **22**. This fourth embodiment may also include any of the relevant subject matter of dependent claims **2**, **5**, **7** and **9-10** as originally filed.

As illustrated in FIG. **9**, in this fourth embodiment, a method **200** of navigation for one or more vehicles **22** located within the control volume **24** includes: (i) at step **210**, observing, with a camera **40** having a known camera spatial position SP_{40}, the one or more vehicles **22** and first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ within a first field of view **45**, wherein the first and second reference points $\mathbf{30}_A$, $\mathbf{30}_B$ have first and second known spatial positions SP_A, SP_B, respectively; (ii) at step **220**, producing, by the camera **40**, an output signal **44** from the observed vehicles **22** and reference points **30**; (iii) at step **230**, transmitting, by a transceiver **51** having a known transceiver spatial position SP_{51}, rangefinding energy $\mathbf{53}_{TX}$ into the control volume **24**; (iv) at step **240**, receiving, by the transceiver **51**, a respective return signal $\mathbf{53}_{RX}$ from each of the one or more vehicles **22** indicative of a respective distance measurement M from the transceiver **51** to each respective vehicle **22**; and; (v) at step **270**, determining, by a processor **60** operatively connected with the camera **40** and transceiver **51**, a respective spatial position SP for each of the one or more vehicles **22** from (i) the output signal **44**, (ii) at least one of the respective return signal $\mathbf{53}_{RX}$ and the respective distance measurement M, and (iii) the known camera and transceiver spatial positions SP_{40}, SP_{51}.

The method **200** of the fourth embodiment may further include one or more of: (vi) at step **250**, determining respective first two-dimensional coordinates **61** of each of the one or more vehicles **22** using the output signal **44**, the first and second known spatial positions SP_A, SP_B, and the known camera spatial position SP_{40}; (vii) at step **260**, determining a distance measurement M from the transceiver **51** to each of the one or more vehicles **22** using the respective return signals $\mathbf{53}_{RX}$; (viii) at step **280**, transmitting one or more messages **72** into the control volume **24**, wherein the one or more messages **72** contain a respective set of three-dimensional spatial coordinates **69** for each of the one or more vehicles **22**; and (ix) at step **290**, receiving a respective vehicle identification **21** transmitted from a respective vehicle beacon **29** carried aboard each of the one or more vehicles **22**.

In the third and fourth embodiments, the transceiver **51** may produce an output signal **54** representative of or containing the distance measurement(s) M from the transceiver **51** to each vehicle **22** within the control volume **24** which has been targeted by the transceiver **51**. (Here "targeted" it is meant that rangefinding EM energy $\mathbf{53}_{TX}$ has been transmitted or directed at a vehicle **22** and a return signal of EM energy $\mathbf{53}_{RX}$ has been received back from the vehicle **22** by the transceiver **51**.) The distance measurement(s) M may be displayed, manipulated or characterized as human-readable alphanumeric information or as machine-readable information (e.g., binary code, hexadecimal code, sequences and amplitudes of varying voltages, etc.), as represented by reference numeral **67** in FIGS. **4**, **5** and **7**.

Note that in any of the embodiments above, each of the control volume **24**, the first, second and third reference points $\mathbf{30}_A$, $\mathbf{30}_B$, $\mathbf{30}_C$, the first and second cameras/receivers **40**, **50** and the transceiver **51** may be configured to be stationary or moving (e.g., with respect to the origin **26**). Also, over time the control volume **24** may expand and/or contract in size and may change in shape. When one or more of the control volume **24**, the reference points **30**, the cameras/receivers **40**, **50** and the transceiver **51** is/are moving (whether translationally, rotationally or otherwise), it may be necessary to know or determine one or more vectors, motion paths (versus time) and/or other data and information relating to one or more of the moving and stationary objects in order to determine the spatial positions SP of each vehicle **22** within the control volume **24**.

The above description is intended to be illustrative, and not restrictive. While the dimensions and types of materials described herein are intended to be illustrative, they are by no means limiting and are exemplary embodiments. In the following claims, use of the terms "first", "second", "top", "bottom", etc. are used merely as labels, and are not intended to impose numerical or positional requirements on their objects. As used herein, an element or step recited in the singular and preceded by the word "a" or "an" should be understood as not excluding plural of such elements or steps, unless such exclusion is explicitly stated. Also, elements of some embodiments may be added to other embodiments or substituted for other elements in such other embodiments. Additionally, the phrase "at least one of A and B" and the phrase "A and/or B" should each be understood to mean "only A, only B, or both A and B". Moreover, unless explicitly stated to the contrary, embodiments "comprising" or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property. And when broadly descriptive adverbs such as "substantially" and "generally" are used herein to modify an adjective, these adverbs mean "for the most part", "to a significant extent" and/or "to a large degree", and do not necessarily mean "perfectly", "completely", "strictly" or "entirely". Additionally, the word "proximate" may be used herein to describe the location of an object or portion thereof with respect to another object or portion thereof, and/or to describe the positional relationship of two objects or their respective portions thereof with respect to each other, and may mean "near", "adjacent", "close to", "close by", "at" or the like.

The flowcharts and block diagrams in the drawings illustrate the architecture, functionality and/or operation of possible implementations of systems, methods and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment or portion of code, which includes one or more executable instructions for implementing the specified logical function(s). It will also be noted that each block of the block diagrams and/or flowchart illustrations, and combinations of blocks in the block diagrams and/or flowchart illustrations, may be implemented by hardware-based systems that perform the specified functions or acts, or combinations of hardware and computer instructions. These computer program instructions may also be stored in a computer-readable medium that can direct a controller or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable medium produce an article of manufacture including instruc-

tions to implement the functions and/or actions specified in the flowcharts and block diagrams.

This written description uses examples, including the best mode, to enable those skilled in the art to make and use devices, systems and compositions of matter, and to perform methods, according to this disclosure. It is the following claims, including equivalents, which define the scope of the present disclosure.

What is claimed is:

1. A navigation system for one or more vehicles located within a control volume, comprising:

a first camera configured to observe the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively, the first camera being further configured to produce a first output signal from observation of the observed vehicles and reference points;

a second camera configured to observe the one or more vehicles and the first, second and third reference points within a second field of view, the second camera being further configured to produce a second output signal from observation of the observed vehicles and reference points; and

a processor operatively connected with the first and second cameras and configured to determine a respective spatial position for each of the one or more vehicles from the first and second output signals;

wherein the one or more vehicles and the control volume are, respectively, one or more aircraft and a landing zone including a first airspace above the landing zone, one or more ground vehicles and an area of terrain including a second airspace above the terrain, one or more surface watercraft and a region of open water including a third airspace above the open water, one or more submersible watercraft and a volume of navigable water, or one or more spacecraft and a volume of navigable space.

2. The navigation system of claim **1**, wherein each of the first, second and third known spatial positions is a respective set of x, y and z coordinates.

3. The navigation system of claim **1**, wherein each of the first, second and third known spatial positions is known with respect to an origin located within the control volume.

4. The navigation system of claim **1**, wherein each of the first and second cameras is configured to detect at least one of visible light, infrared light and ultraviolet light.

5. The navigation system of claim **1**, wherein the first and second cameras are disposed such that their respective fields of view are generally orthogonal with each other.

6. The navigation system of claim **1**, wherein each of the first, second and third reference points is (i) a respective point on a respective physical object disposed within the control volume and/or (ii) a respective focal point of a respective reference point beacon disposed within the control volume.

7. The navigation system of claim **1**, wherein the first output signal is representative of a first two-dimensional image of the control volume as viewed from the first camera, and wherein the second output signal is representative of a second two-dimensional image of the control volume as viewed from the second camera.

8. The navigation system of claim **1**, further comprising:

a transmitter operatively connected with the processor and configured to transmit one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles.

9. The navigation system of claim **1**, further comprising:

a first real-time tracking system operatively connected with the first camera for determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions; and

a second real-time tracking system operatively connected with the second camera for determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions.

10. The navigation system of claim **1**, further comprising:

a respective vehicle beacon configured to be carried aboard each of the one or more vehicles, wherein each vehicle beacon is configured to transmit a respective vehicle identification.

11. A navigation system for one or more vehicles located within a control volume, comprising:

a first camera configured to observe the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively, and wherein each of the first, second and third known spatial positions is known with respect to an origin located within the control volume, the first camera being further configured to produce a first output signal from observation of the observed vehicles and reference points, wherein the first output signal is representative of a first two-dimensional image of the control volume as viewed from the first camera;

a second camera configured to observe the one or more vehicles and the first, second and third reference points within a second field of view, the second camera being further configured to produce a second output signal from observation of the observed vehicles and reference points, wherein the second output signal is representative of a second two-dimensional image of the control volume as viewed from the second camera;

a processor operatively connected with the first and second cameras and configured to determine a respective spatial position for each of the one or more vehicles from the first and second output signals; and

a transmitter operatively connected with the processor and configured to transmit one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles;

wherein the one or more vehicles and the control volume are, respectively, one or more aircraft and a landing zone inducing a first airspace above the landing zone, one or more ground vehicles and an area of terrain including a second airspace above the terrain, one or more surface watercraft and a region of open water including a third airspace above the open water, one or more submersible watercraft and a volume of navigable water, or one or more spacecraft and a volume of navigable space.

12. The navigation system of claim **11**, wherein each of the first, second and third known spatial positions is a respective set of x, y and z coordinates.

13. The navigation system of claim **11**, wherein the first and second cameras are disposed such that their respective fields of view are generally orthogonal with each other.

14. The navigation system of claim 11, further comprising:

a respective vehicle beacon configured to be carried aboard each of the one or more vehicles, wherein each vehicle beacon is configured to transmit a respective vehicle identification.

15. The navigation system of claim 11, further comprising:

a first real-time tracking system operatively connected with the first camera for determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions; and

a second real-time tracking system operatively connected with the second camera for determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions.

16. A method of navigation for one or more vehicles located within a control volume, comprising:

observing, with a first camera, the one or more vehicles and first, second and third reference points within a first field of view, wherein the first, second and third reference points have first, second and third known spatial positions, respectively;

producing, by the first camera, a first output signal from observation of the observed vehicles and reference points;

observing, with a second camera, the one or more vehicles and the first, second and third reference points within a second field of view;

producing, by the second camera, a second output signal from observation of the observed vehicles and reference points; and

determining, by a processor operatively connected with the first and second cameras, a respective spatial position for each of the one or more vehicles from the first and second output signals;

wherein the one or more vehicles and the control volume are, respectively, one or more aircraft and a landing zone including a first airspace above the landing zone, one or more ground vehicles and an area of terrain including a second airspace above the terrain, one or more surface watercraft and a region of open water including a third airspace above the open water, one or more submersible watercraft and a volume of navigable water, or one or more spacecraft and a volume of navigable space.

17. The method of claim 16, further comprising:

determining respective first two-dimensional coordinates of each of the one or more vehicles using the first output signal and the first, second and third known spatial positions; and

determining respective second two-dimensional coordinates of each of the one or more vehicles using the second output signal and the first, second and third known spatial positions.

18. The method of claim 16, further comprising:

transmitting one or more messages into the control volume, wherein the one or more messages contain a respective set of three-dimensional spatial coordinates for each of the one or more vehicles.

19. The method of claim 16, further comprising:

receiving a respective vehicle identification transmitted from a respective vehicle beacon carried aboard each of the one or more vehicles.

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